Understanding and Improving Pinning in Coated Conductors
Part II: Improving Pinning

Home

Help

Summary

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Plans which were put forward for 2004

Design and implement systematic experiments to determine if chemical modifications to REBCO offer enhanced performance, particularly in an external magnetic field.
Goal: Reproducibly double J_c at 75 K in a magnetic field parallel to the c-axis.

To grow HTS films with rare earth substitutions.
Goal: to search for pinning enhancements by introduction of random defects.

To introduce columnar defects at different angles in YBCO films on single crystal substrates.
Goal: to measure angular dependence of J_c in samples with a controlled defect structure, for comparison with CC.

Possible practical ways to enhance pinning

Examples of earlier work relevant to this study

- More line defects
  - Miscut substrates — *Lowndes D.H. et al. Phys. Rev. Lett. 74 (12) 2355 (1995)*
  - Lower growth temperatures (smaller island sizes) — *Dam B. et al. Phys. Rev. B 65 (6) 064528 (2002)*
  - Heteroepitaxial nanoparticles — *Huijbregtse J. M., et al., Phys. Rev. B. 62 (2) 1338-1349 (2000)*

- Point defects (and associated strain)
  - cation or anion vacancies
  - RE-Ba cross substitution

- Volume defects (and associated strain)
  - Second phase particles
  - Interlayers of non-superconducting material
  - Substrate surface roughening

Berenov A. et al. J. Mater. Res. 18 956 (2003)

Haugan T. et al., J. Mater. Res. 18 (11) 2618 (2003)

Jia Q.X. et al., APL 80 (9) 1601 (2002)

Four different routes to enhanced pinning demonstrated

Method 1. Change RE ion size variance

- introduces random point defects

Method 2. Change average RE ion size

- introduces random points defects and correlated defects

Method 3. Introduction of buffer surface roughness

- more low angle grain boundaries || c

Method 4. Introduction of heteroepitaxial second phases

- increase c-axis dislocation density

Substrates used were single crystal $SrTiO_3$, $SrTiO_3$-buffered single crystal MgO and $SrTiO_3$-buffered IBAD MgO. Films around 1-1.5 μm thick. Growth by PLD, standard YBCO conditions used for all samples.

Methods 1 and 2: Applying a systematic approach to studying mixed REBCO's.

• The aim is to apply a systematic approach to mixing RE ions.
(Changing growth T, pO_2, or mixing ratio are not structurally systematic)

• We deliberately paid no attention to increasing T_c above that for YBCO because much higher (and therefore not practical) growth temperatures are required for the higher T_c RE's. All our samples had the same or lower T_c than YBCO.

• We studied the influence of RE ion size variance and RE ion size separately

Method 1: Change RE ion size variance for constant RE ion size
Method 2: Change RE ion size for constant RE ion size variance

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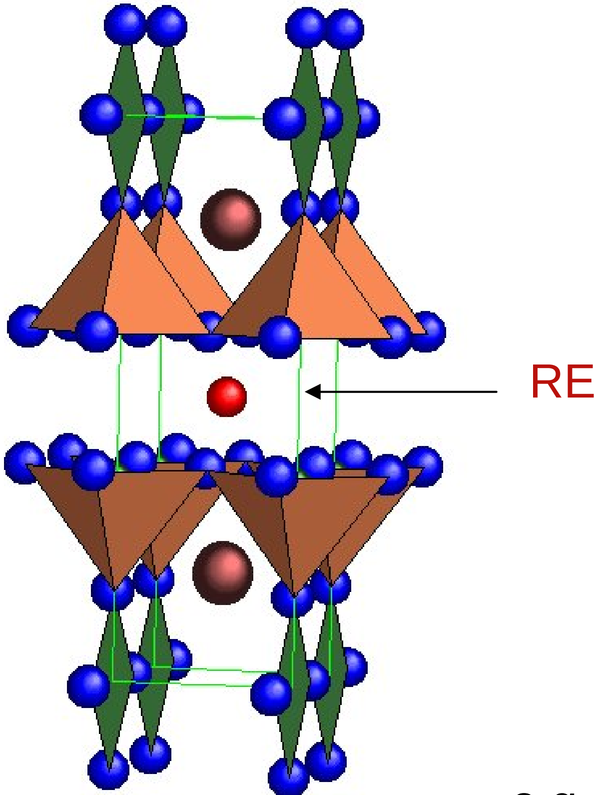
Change ion size variance, and keep mean ionic radius constant



$$\boxed{\sigma^2 = \Sigma y_i \langle r_i \rangle^2 - \langle r_A \rangle^2}$$

where σ^2 is the variance of the mixture of RE ions i

y_i is the mole fraction of ion i

r_i is the ionic radius if ion i

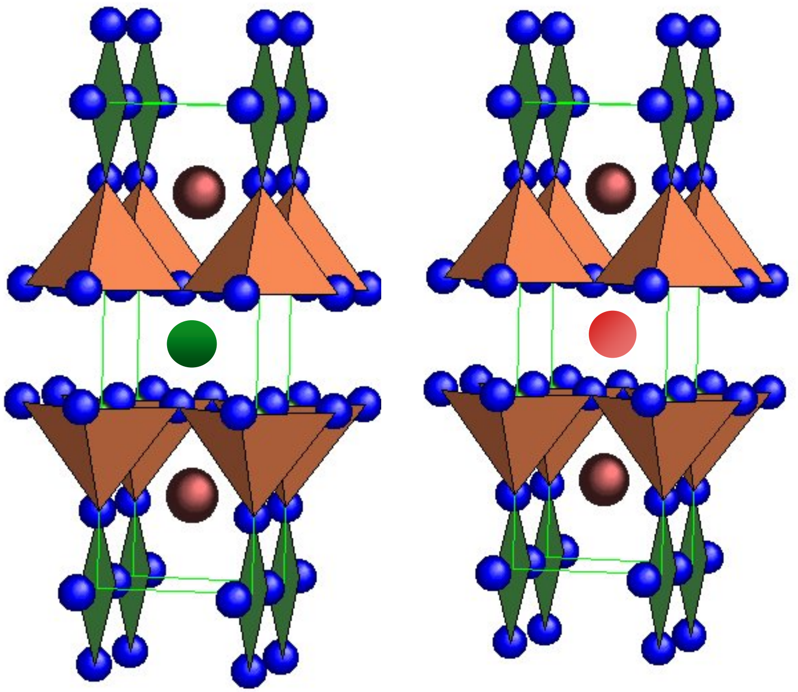
r_A is the mean ionic radius

$\langle r_A \rangle$ = 1.019Å, i.e. the ionic radius was <u>kept constant</u> at the size of Y^{3+}

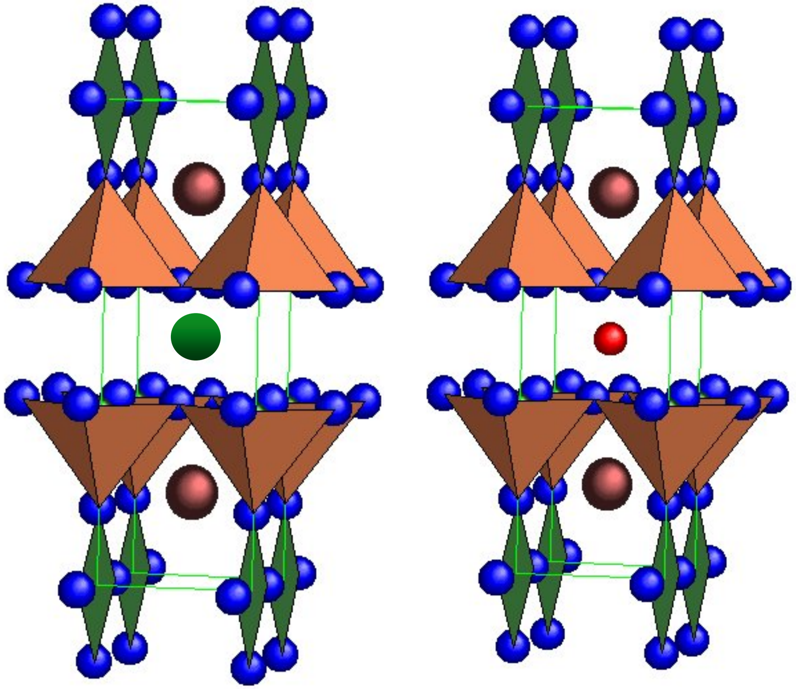
e.g. for the composition $Dy_{1/3}Ho_{2/3}BCO$

$$\sigma^2 = [1/3(1.027^2) + 2/3(1.015^2)] - 1.019^2 = 0.32x10^{-4}\,Å^2$$

Method 1: Change RE ion size variance
Aim is to produce random variations in oxygen ion displacements



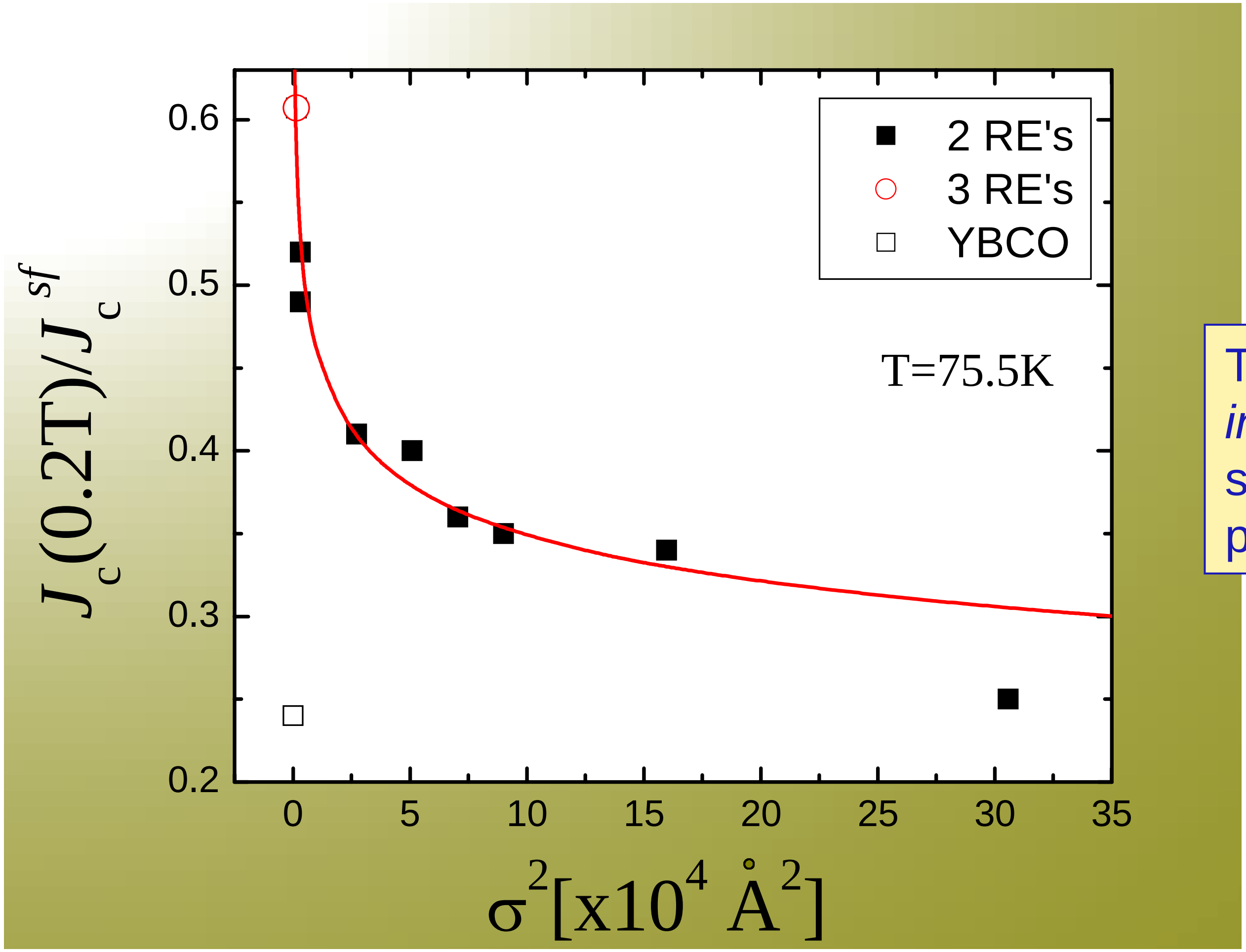
small variance



large variance

Changing RE ion size does not change Cu(2)-O(2) plane buckling but increases the Cu(2)-O(1) distance by ~2.5% across the RE series

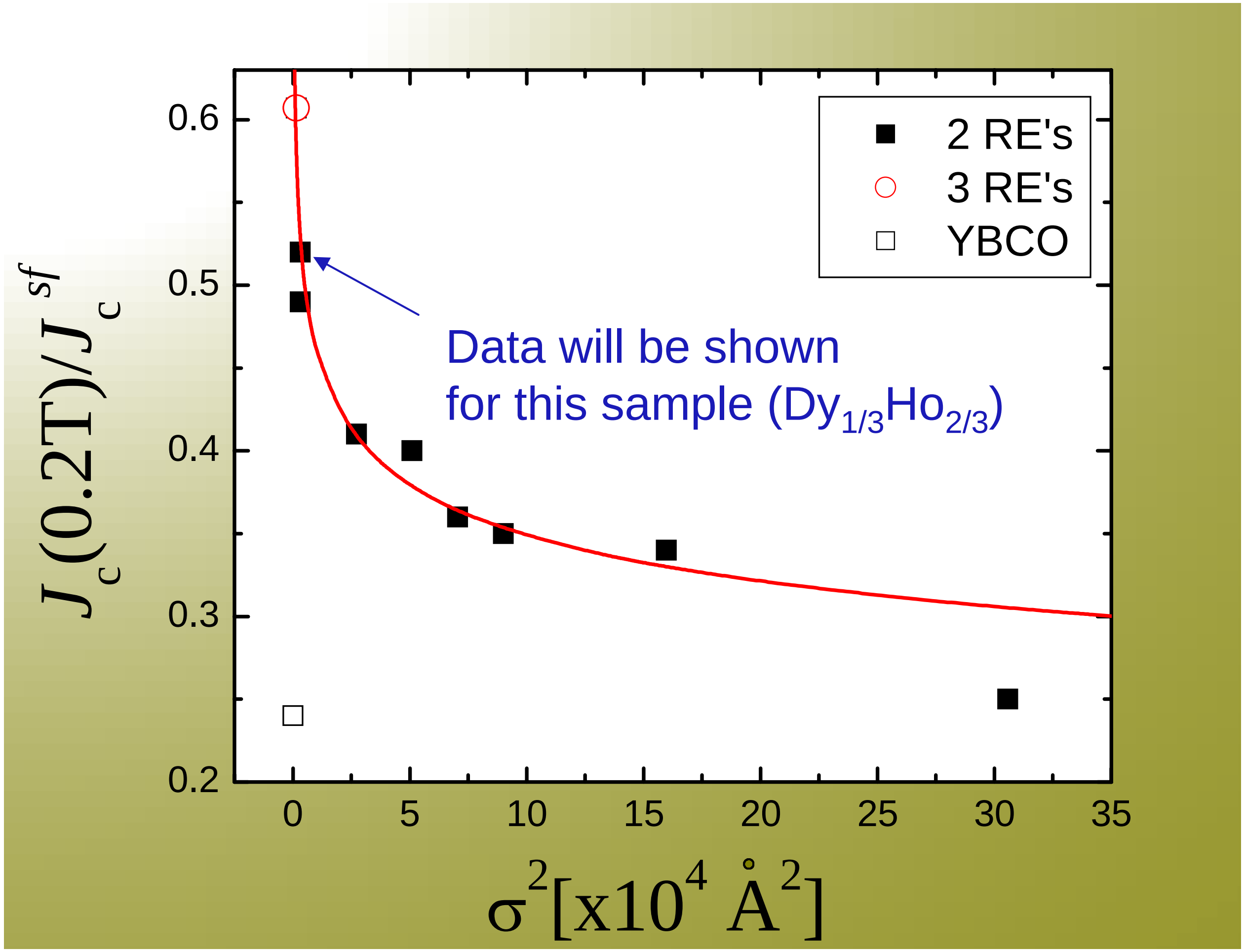
There is a Systematic, Reproducible, and Improved Dependence of Low Field Pinning on RE Ion Size Variance



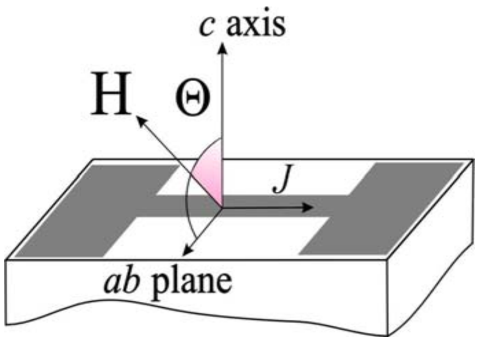
The variance effect is *intrinsic* and hence should work for any processing route.

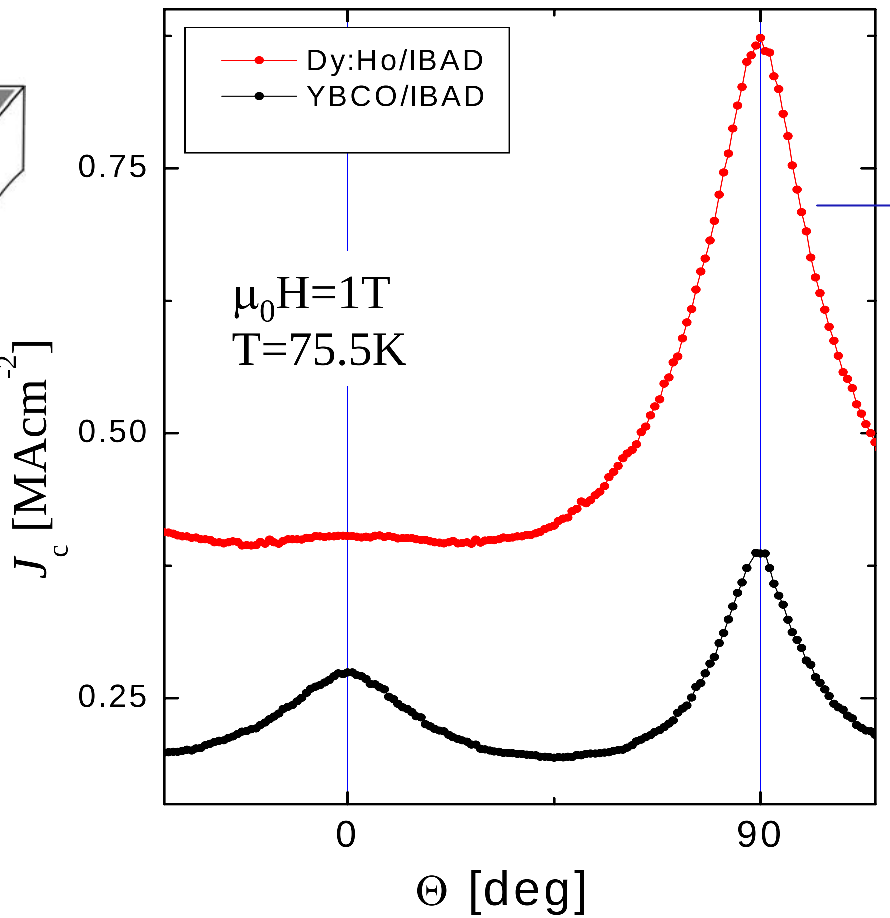
J.L. MacManus-Driscoll et al. APL ***84*** *(26) (2004) 5329*

There is a Systematic and Reproducible Dependence of Low Field Pinning on RE Ion Size Variance



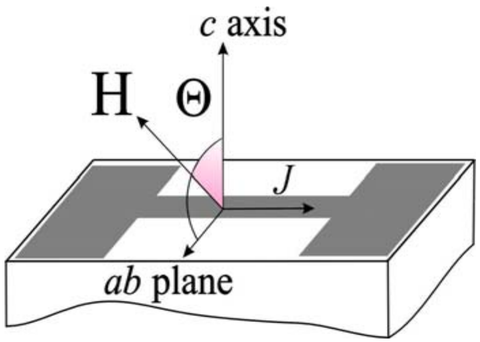
Field angular measurements indicate that random, point-like defects responsible for increased J_c

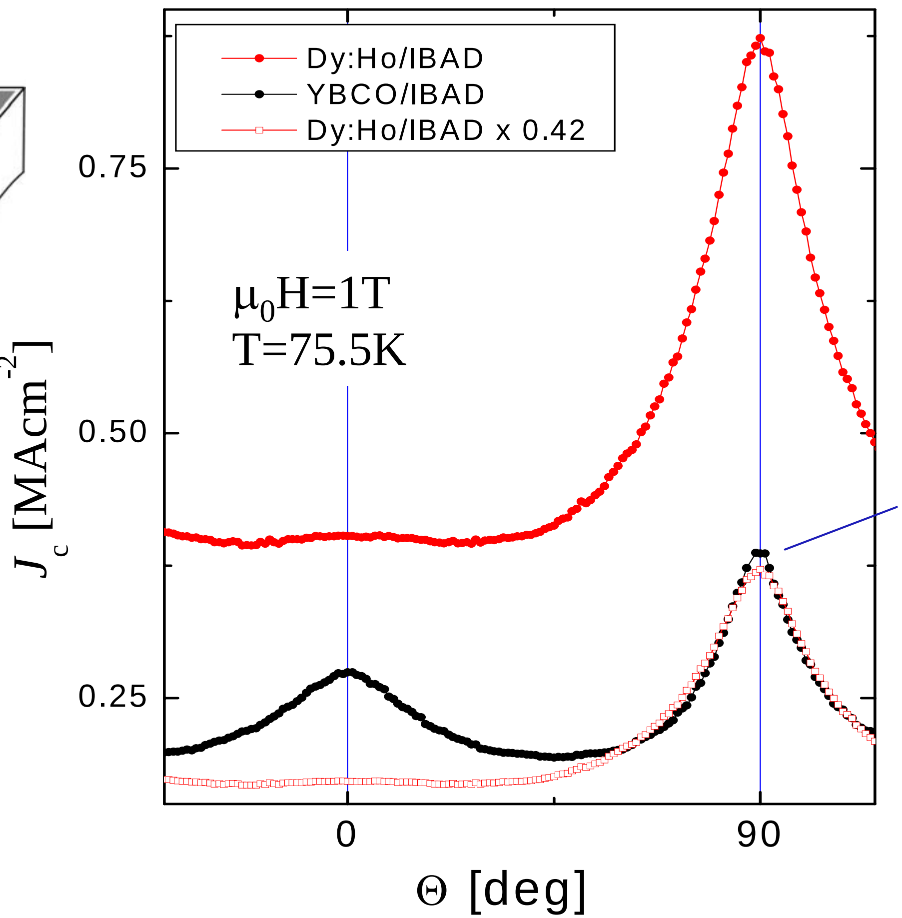




Optimum variance sample has improved J_c over wide field and angular range

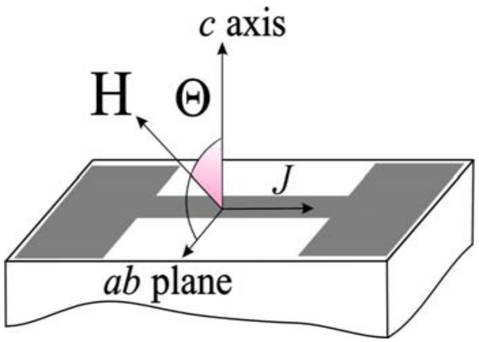
Field angular measurements indicate that random, point-like defects responsible for increased J_c

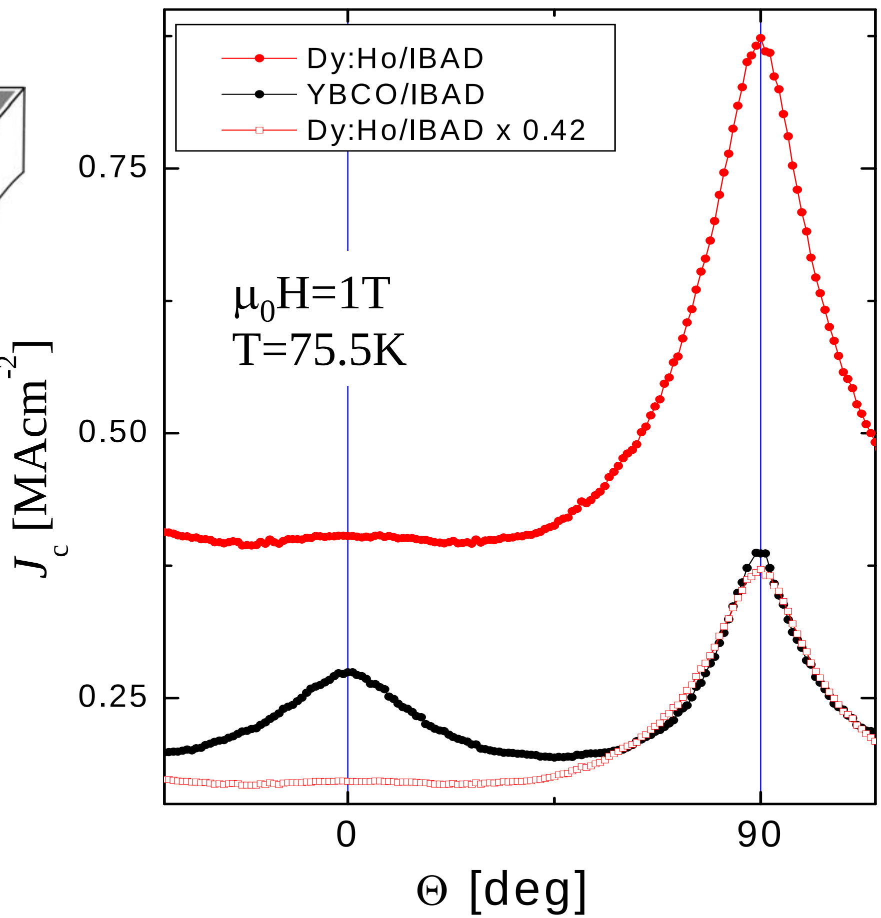




Normalisation indicates non-correlated, random, point-like defects present

Field angular measurements indicate that random, point-like defects responsible for increased J_c



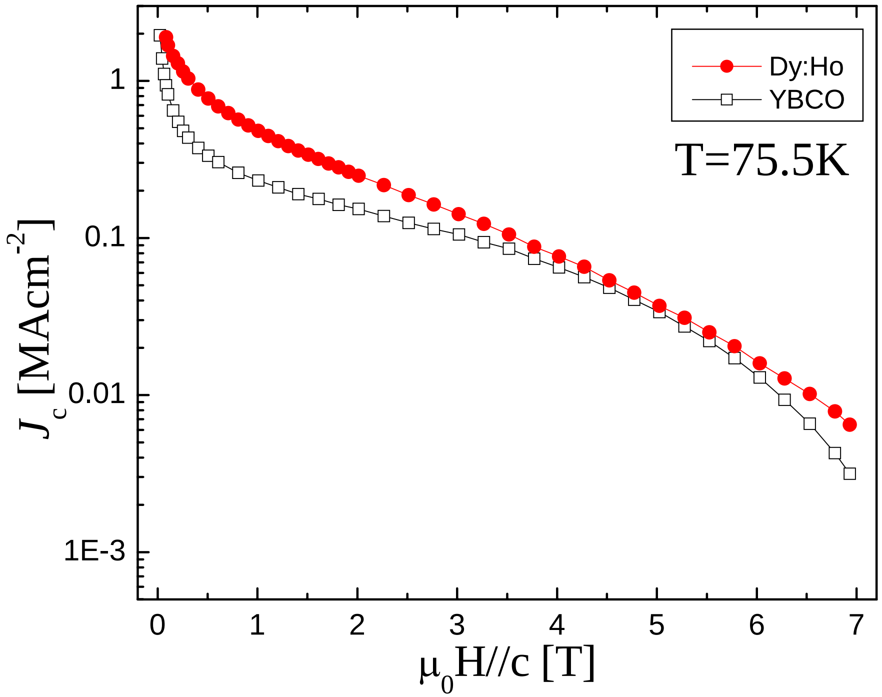


The results are consistent with earlier studies on magnetoresistive and ferroelectric perovskites ⇒ Ion size variance produces *random* displacements of oxygen ions

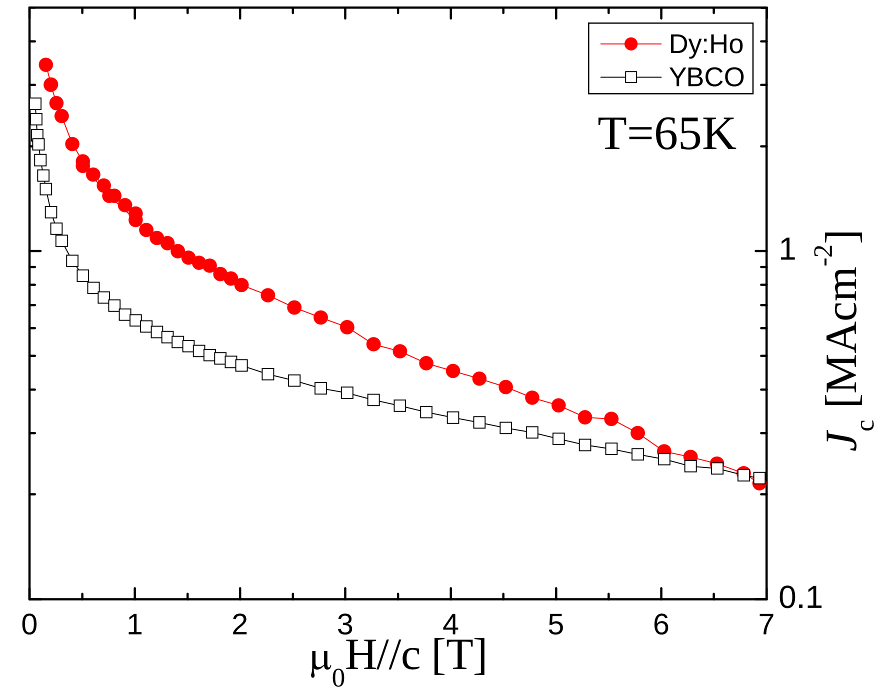
(L. M. Rodriguez- Martinez, and J.P. Attfield, Phys. Rev. B 54 (22) (1996) R15 622)

J_c versus field improved by up to a factor of 2 for lowest variance sample

Low ion size variance improves field dependence to 4T at 75.5K



Low ion size variance improves field dependence to 6T at 65K



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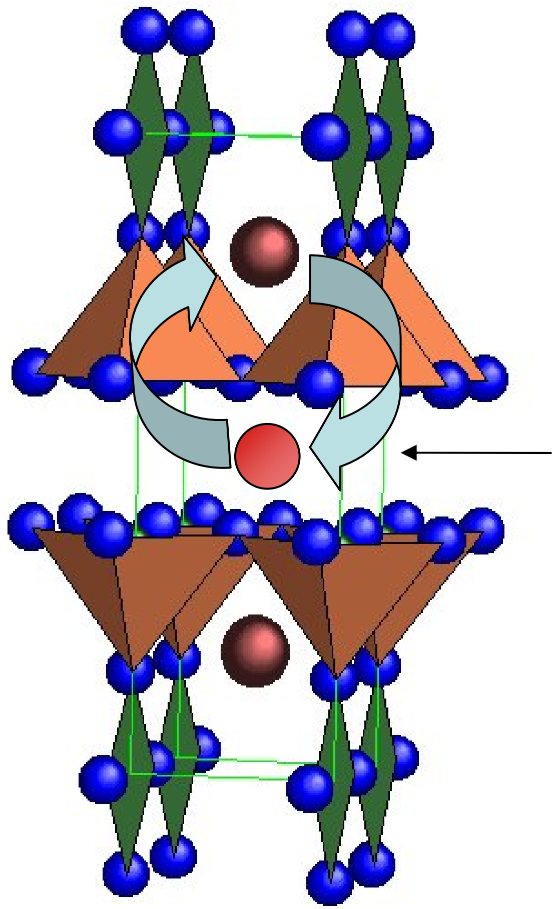
Substrates used were single crystal $SrTiO_3$, $SrTiO_3$-buffered single crystal MgO and $SrTiO_3$-buffered IBAD MgO. Films around 1-1.5 μm thick. Growth by PLD, standard YBCO conditions used for all samples.

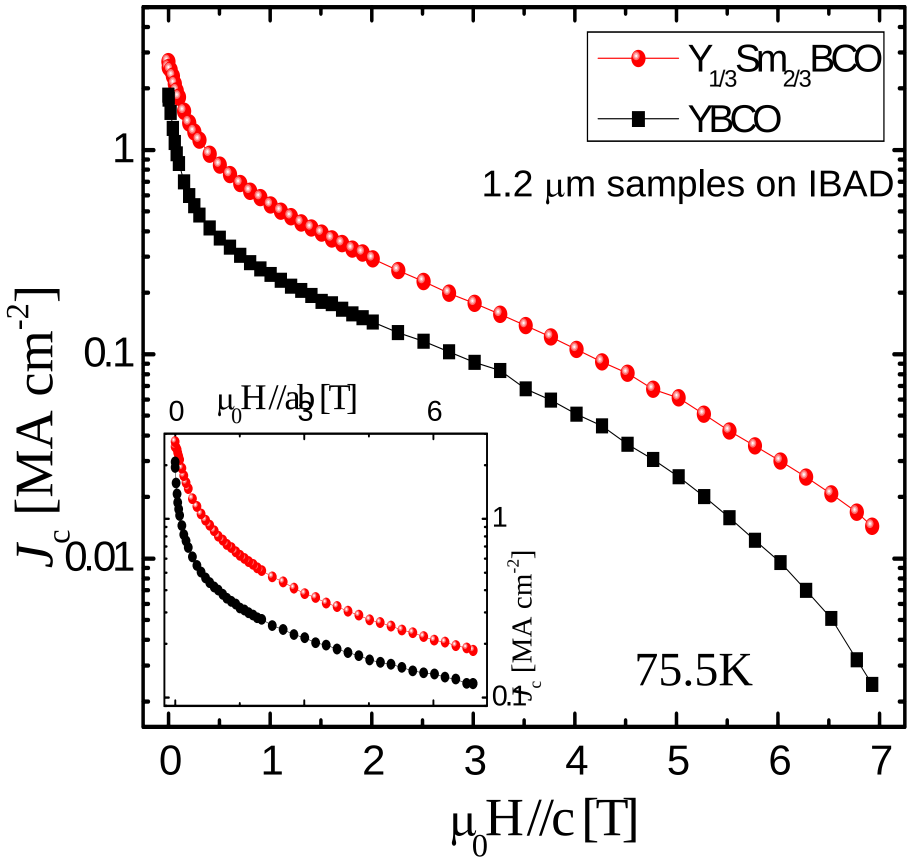
Method 2: Increase average RE ion size, keep variance constant

We find no systematic dependence of pinning on RE ion size. This is not surprising since the amount of Y-Ba cross substitution is strongly dependent on kinetics which are not easily controlled.



average RE bigger

J_c of $Y_{1/3}Sm_{2/3}BCO$ (<r_A>=1.039Å) is much improved compared to YBCO (<r_A>=1.019Å). σ^2 = 6-8 x 10^{-4} Å^2



On STO: Self-field J_c up to 5MA.cm^{-2} in 1μm thick films.

On IBAD: J_c (H) improved by a factor of 2-10 (depending on *H*)

The RE ion size effect is *intrinsic* and hence should work for any processing route.

J.L. MacManus-Driscoll et al., submitted APL 6/04

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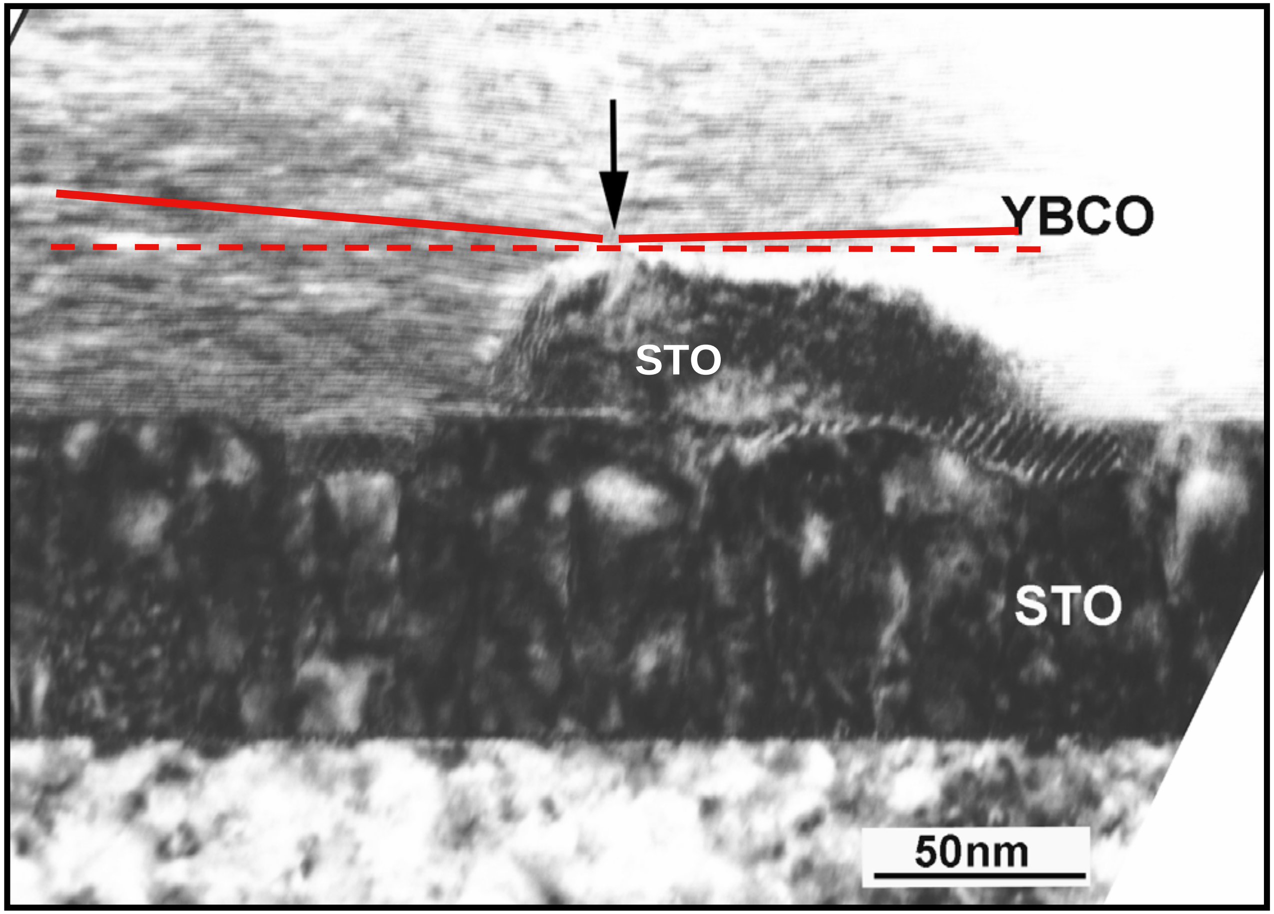
Method 3: Introduction of buffer surface roughness by lower temperature growth introduces *low angle* grain boundaries

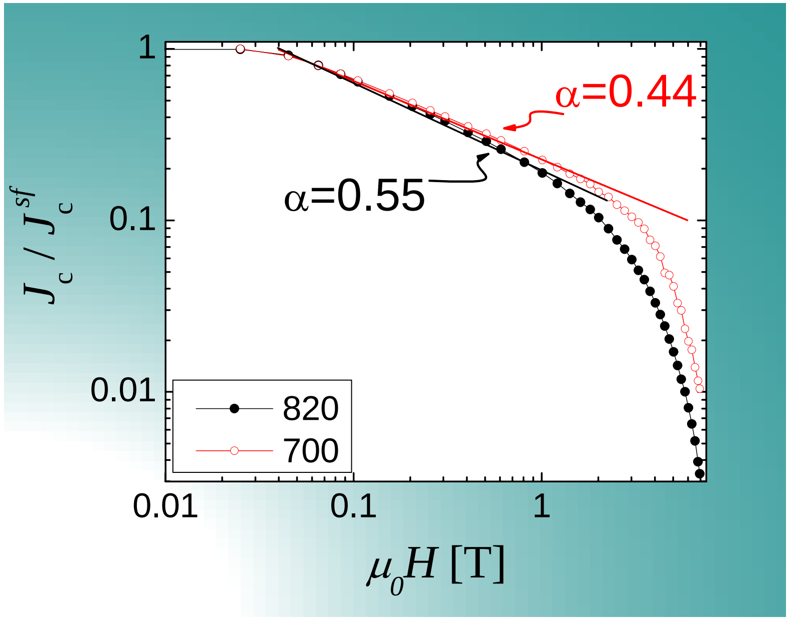


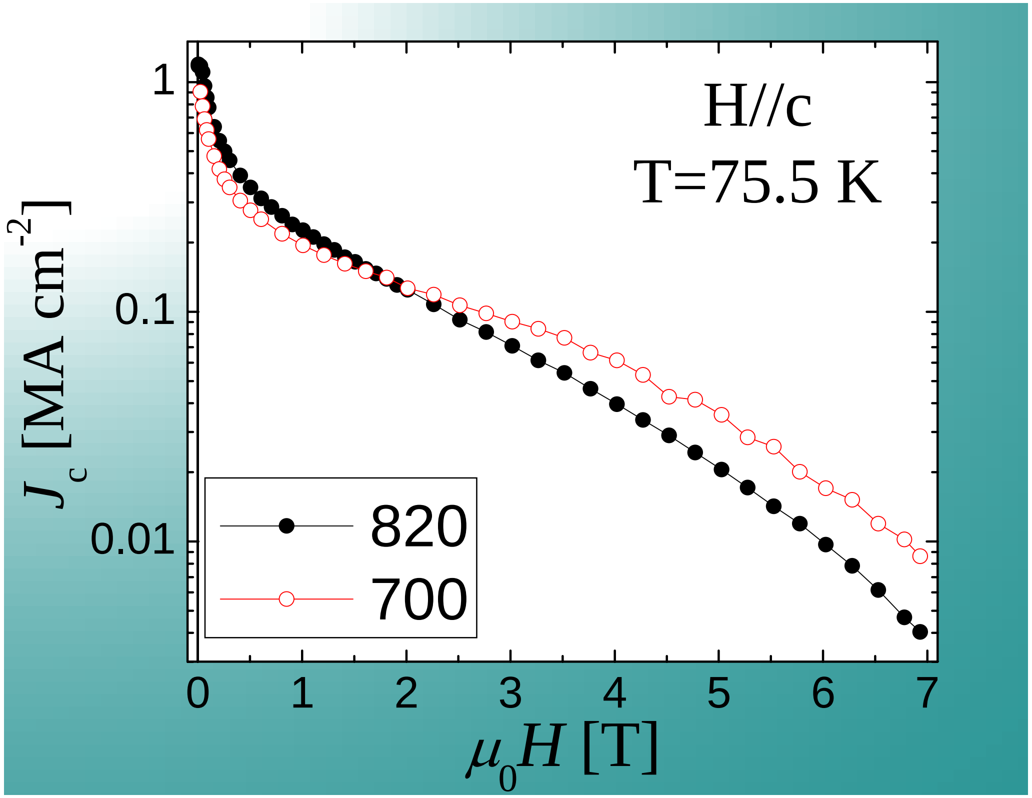
H. Wang et al. J. Mat. Res. 19 (2004) 1869

The *in-field* dependence of J_c is improved in 5μm thick films on IBAD-MgO

T_{STO} = 700 °C cf. T_{STO} = 820 °C

– Lower J_c self-field
– Higher J_c in-field



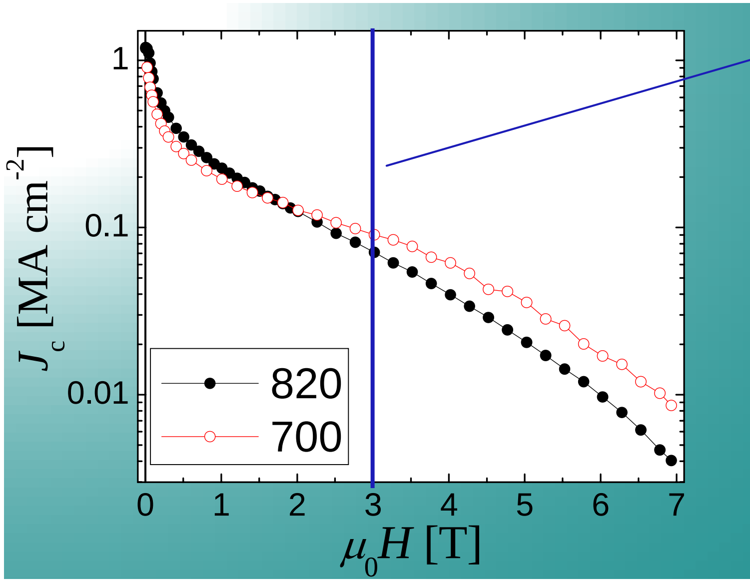


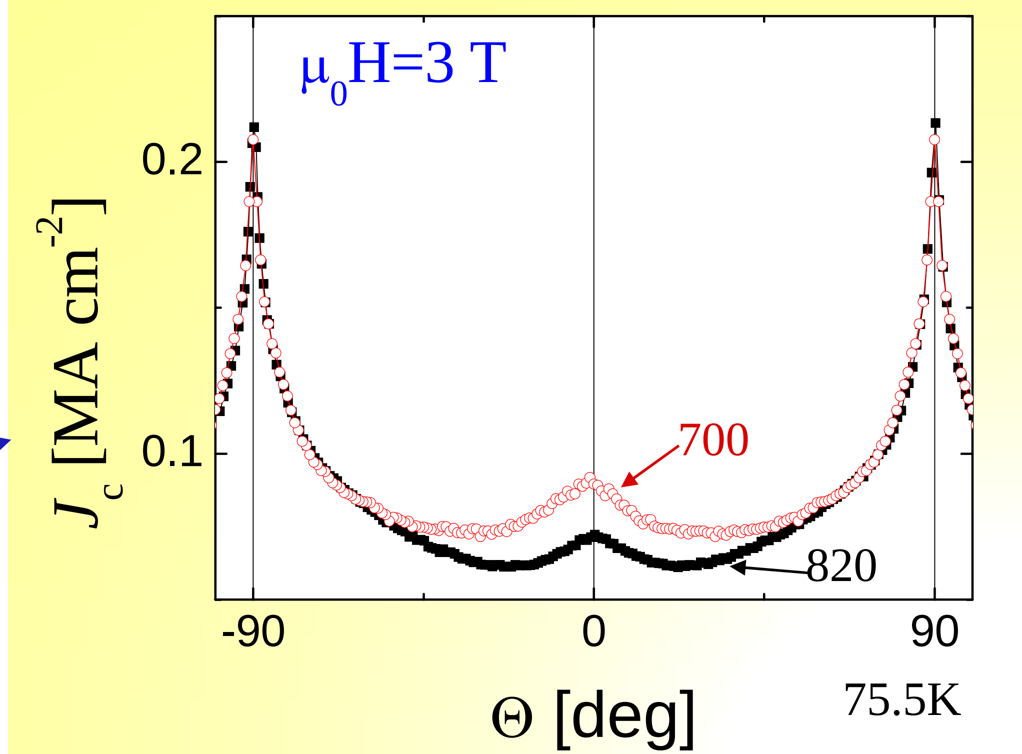
Growth temperature of YBCO was constant at 760°C

B. Maiorov et al. accepted Ceramic Transactions (2004)

The angular dependence of J_c shows a larger c-axis peak

The angular effect is consistent with the presence of <u>low angle</u> boundaries //c (introduced by tilted a-b planes induced by buffer surface roughness)





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Introduction of c-axis dislocations through heteroepitaxial second phases

Materials selection for second phase:

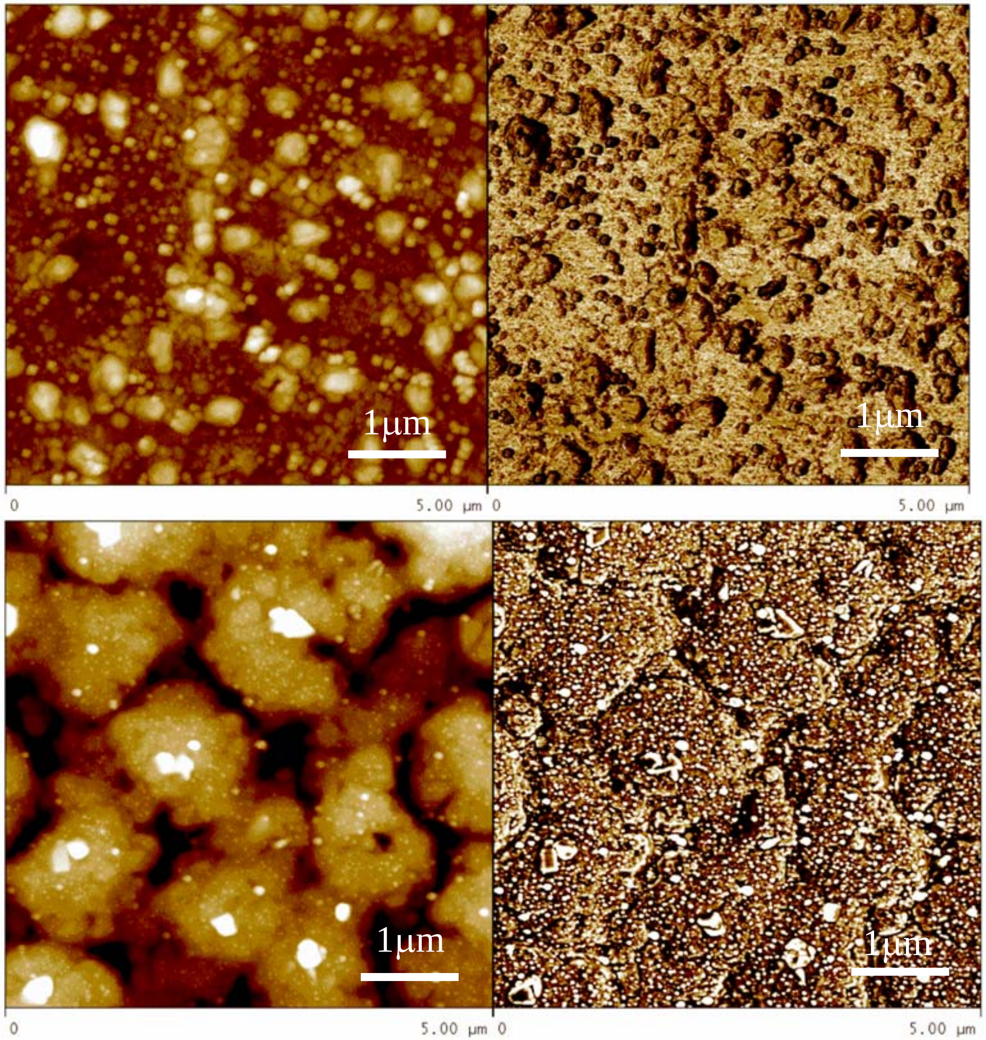
a) Can grow heteroepitaxially with YBCO
b) Lattice mismatch producing strain leading to misfit dislocations
c) High melting temperature phase, yielding slow growth kinetics and hence small particles
d) Chemical compatability with YBCO

Simple method of second-phase incorporation:

- ceramic target of YBCO+ 5 mol% $BaZrO_3$ fabricated and ablated

J.L. MacManus-Driscoll et al. Nature Materials 3 (7 July) (2004) 439

Micrographs of 'YBCO+$BaZrO_3$' shows the presence of surface nano-particles

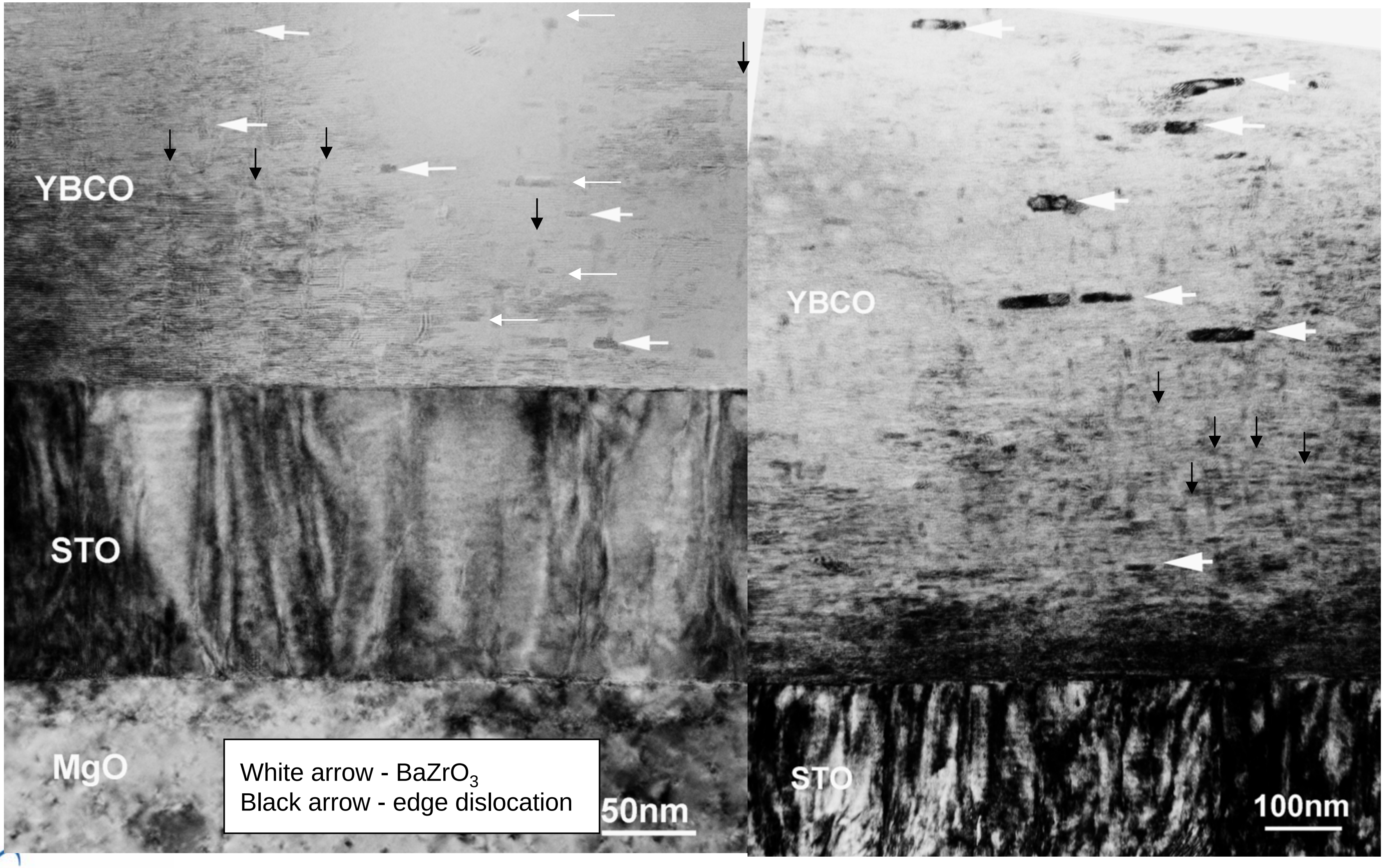


YBCO

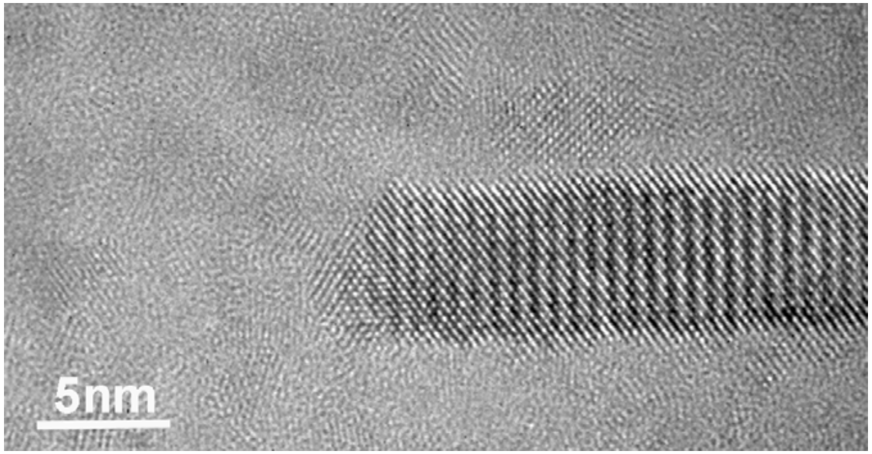
YBCO+$BaZrO_3$

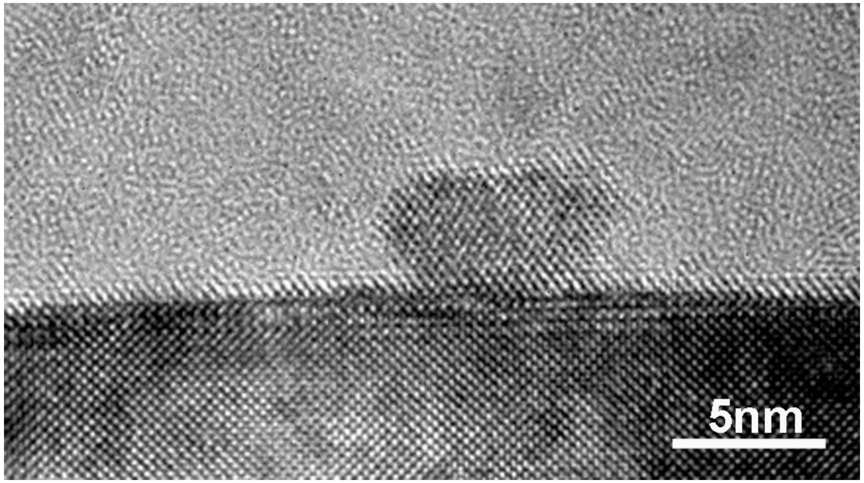
10-100nm surface particles. In bulk too?

TEM shows edge dislocations. Around a 5-fold increase in density of c-axis dislocations (~400 μm^{-2} cf. ~80 μm^{-2})

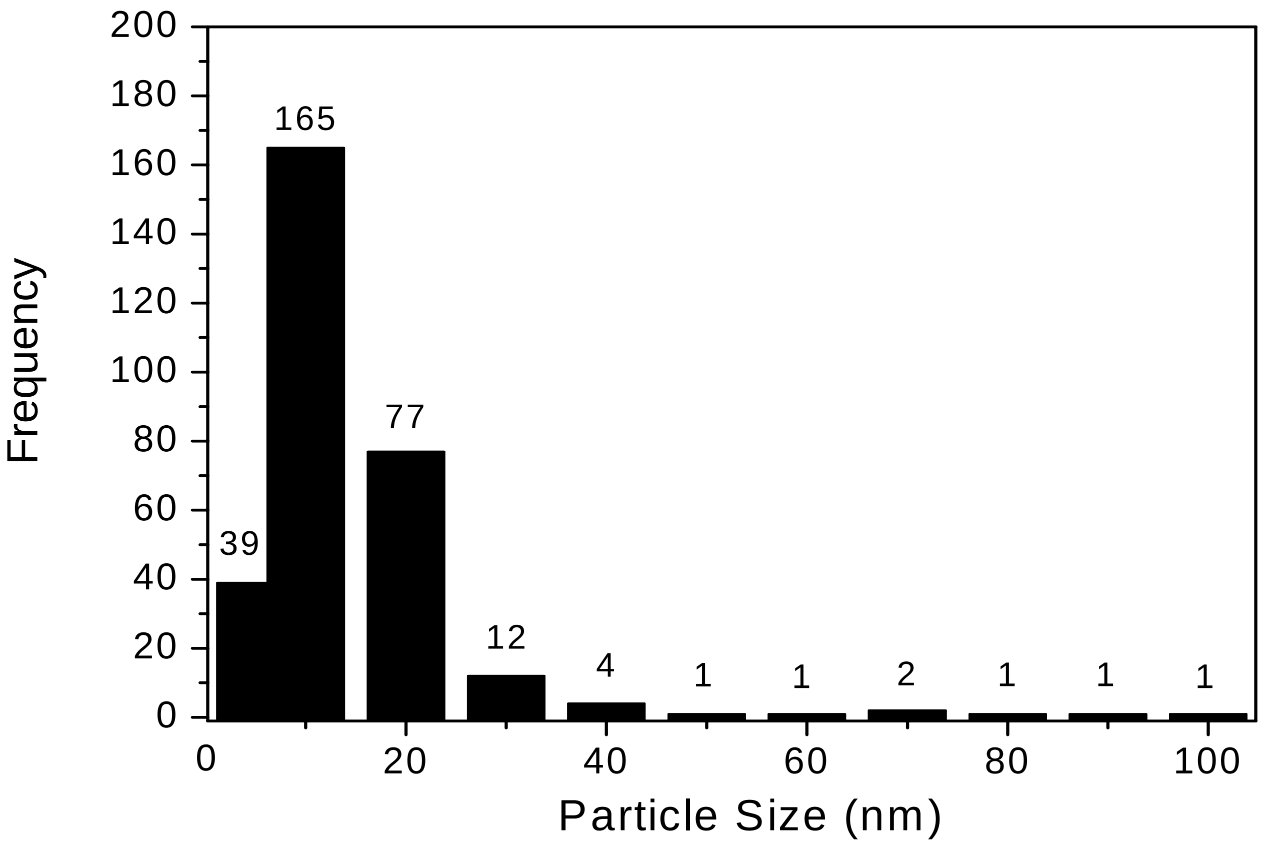


HRTEM and EDX shows the presence of $BaZrO_3$ nano-particles embedded within the film



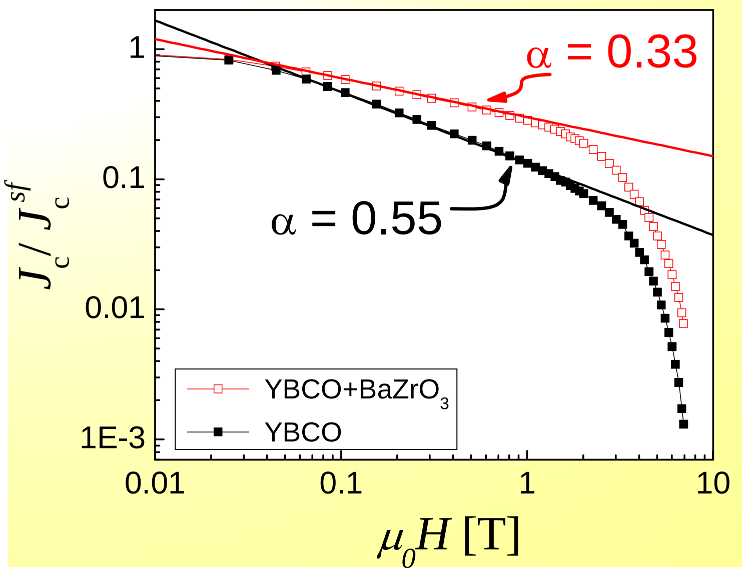


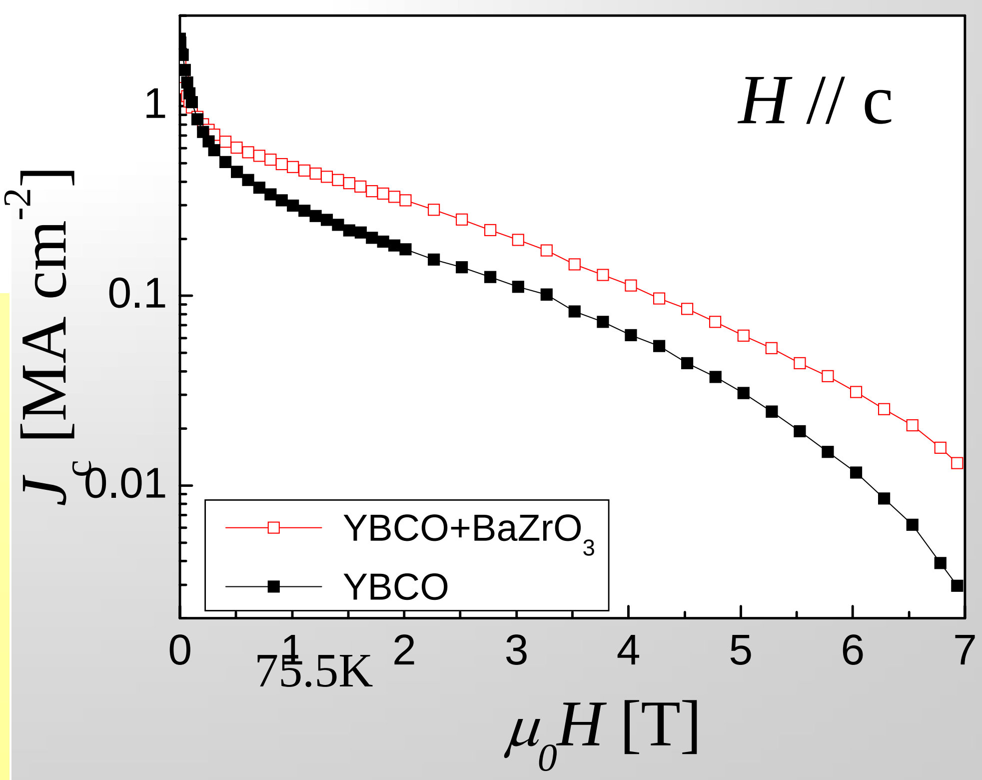
Modal particle size of $BaZrO_3$ is 10 nm



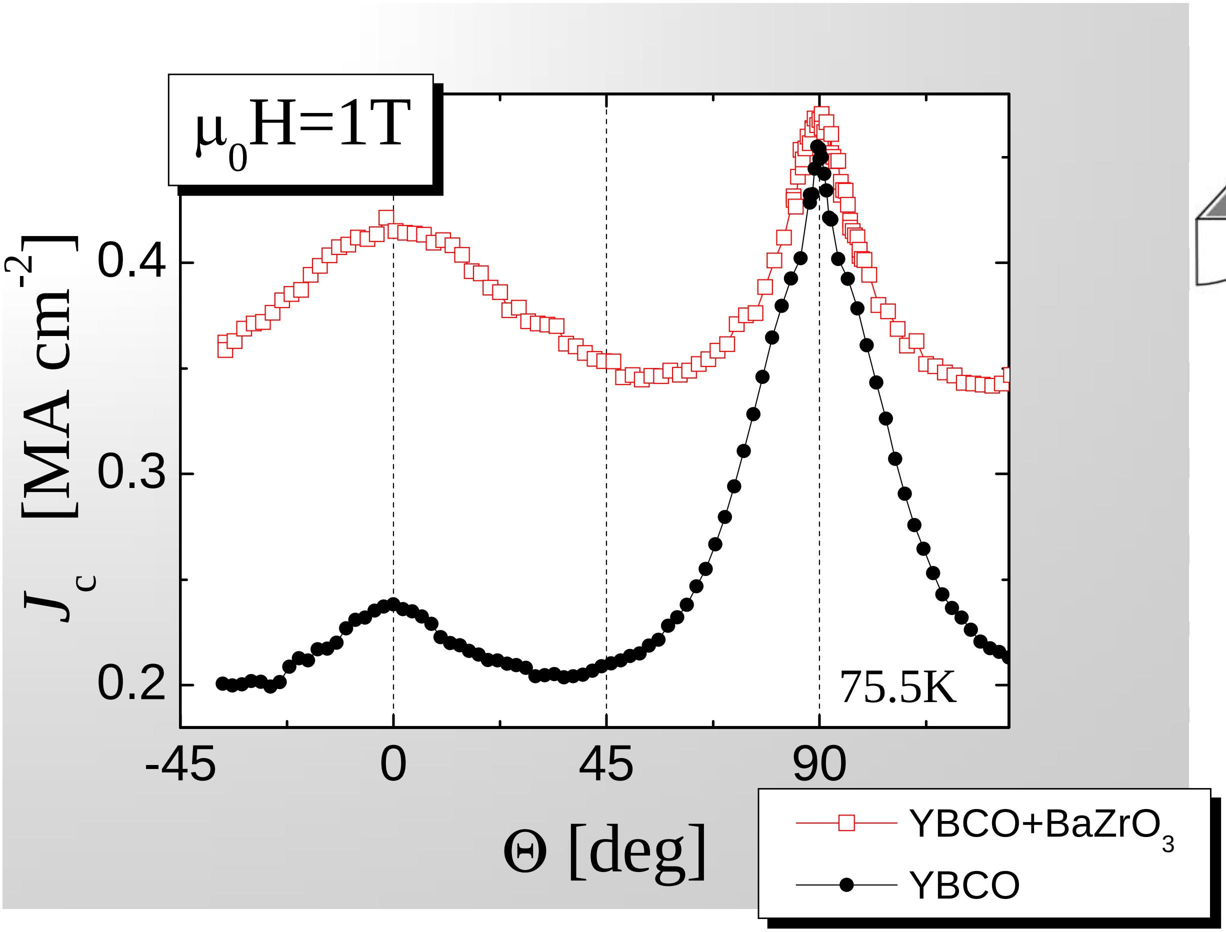
J_c vs. $\mu_0 H$ comparison of YBCO+$BaZrO_3$ and YBCO samples shows a 1.5-5x increase in J_c

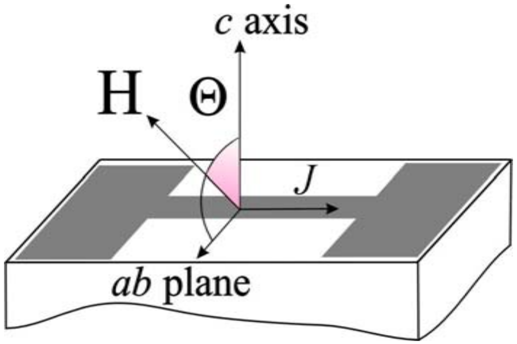
The 'α' value is much lower for YBCO+$BaZrO_3$





Field angular data shows a huge c-axis peak consistent with the additional c-axis dislocations





Conclusions

- Several successful routes have been demonstrated to nano-engineer defects into REBCO to enhance pinning.
  – simple, inexpensive and scaleable technique ablating YBCO and $BaZrO_3$. This yield $BaZrO_3$ nano-particles and extra c-axis dislocations
  – use of small but non-zero RE ion size variance, mixed RE compositions which produce random defects
  – use of mixed RE's which contain Y and Sm which produce random point defects and correlated defects
  – lower growth temperature of buffer producing surface particles which cause a-b planes to tilt and result in low angle grain boundaries parallel to 'c'